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Carburetor Icing as a Source of Flight Safety Hazards

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Abstract

The objective of the study is to assess the impact of carburetor icing on flight safety hazards. The introductory section of the article presents key information on carburetor systems and characterizes the phenomenon of carburetor icing, along with the mechanism of its occurrence. The main portion of the study was based on an analysis of eighteen reports of aviation accidents involving carburetor icing. These reports were selected from the PKBWL (State Commission for Aircraft Accident Investigation of Poland) report database over the past 20 years. The goal of this analysis was to identify the primary factors contributing to such accidents, determine their causes, and propose preventive measures for this type of incident. The following primary causes of carburetor icing were identified: pilots' lack of awareness regarding the existing risk, incorrect beliefs that icing only occurs at subzero temperatures, inadequate training of aviation personnel in recognizing and preventing icing, lack of knowledge on how to operate the carburetor heater, and insufficient pre-flight inspections of the heater system. Based on the analysis, proposals were formulated to mitigate the occurrence of icing. It should be noted that these primarily concern human factors, which were found to be the most significant in the cases studied.

Keywords: Carburetor, Icing, Safety

1. Introduction

The development of aviation has been associated with the need to improve safety for many years. Engineers took all measures to eliminate threats during flight. However, the development and constant revolution in aviation have been correlated with an increase in the number of accidents. People sometimes sacrificed their lives while gaining new experiences in the field of aeronautics, thus contributing to the increase in the reliability of structures and methods of their use.

One of the significant problems contributing to a large number of aviation incidents and accidents is the phenomenon of icing, particularly carburetor icing. When the first piston engines appeared on the aviation market, pilots were unable to cope with many different problems, including icing both on the surface of the aircraft and in the carburetor area. This was due to the low level of knowledge in this area. The continuous increase in the number of incidents resulting from carburetor icing has forced thorough research into this process. It was noticed that ice and frost formed only under certain weather conditions. The main factors contributing to carburetor icing were humidity, temperature, and cloud cover. Back then, the simplest solution seemed to be to avoid flights when unfavorable weather conditions occurred. However, this did not solve the situation. The breakthrough was the introduction of carburetor heating. This resulted in a significant improvement in flight safety, but as it turns out, it does not

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solve all the problems, and dangerous situations continued to occur despite extensive knowledge in this area and the introduction of a number of safeguards.

Determining the causes of air accidents related to carburetor icing and effectively counteracting this phenomenon motivated the authors of this study to undertake a broader analysis of this phenomenon. This was due to the fact that despite the implementation of certain design and educational solutions, incidents still occur at their source, which are caused by carburetor icing. Only traditional piston engine-powered aircraft were taken into account for the study. Helicopters were excluded as a minor group of aircraft subject to this phenomenon.

2. Carburetors structure and characteristics

A carburetor is defined as a device used to prepare the fuel-air mixture flowing into the combustion chamber, typical of spark ignition engines. It was constructed by Gottlieb Daimler in 1876. Today, it is primarily used as a component of aircraft engines. The carburetor consists of a special pipe that supplies air from the filter to the engine and a transversely located pipe through which fuel is supplied, as well as a system that maintains a constant fuel level. This structure illustrates a basic carburetor, containing its most important parts. The principle of operation of this device is that the cylinders create a vacuum, which generates underpressure due to the Bernoulli effect. This underpressure causes fuel to enter the carburetor throat, facilitating the preparation of the fuel-air mixture. The engine continuously draws in air from the outside, which pulls fuel from the nozzles located in the passageway. Then, the fuel is burned in the cylinders (Chachurski, 2013).

Three types of carburetors are commonly used in aviation: a diaphragm carburetor with a tilting throttle, a float carburetor with a piston throttle, and a carburetor with a variable throat cross-sectional area and a tilting throttle. The first type can be found in small two-stroke engines. It includes a throttle, an idle nozzle, and a main nozzle. After starting the engine, it runs at idle speed. By increasing the engine power by gradually opening the throttle, the fuel flow to the idle nozzle is blocked, while the main nozzle begins to operate. When the throttle is fully opened, the diaphragm blocks the fuel flow to the slow-speed nozzle while leaving the main nozzle fully open (Grzelka et al., 2013).

The second type of carburetor drives high-speed engines, such as paragliders and ultralight aircraft engines. An additional element of its construction is a slot at the bottom of the throttle, which supplies air at idle speed. The main difference in the operation of carburetors in this group is the ability to open or close the piston, which regulates the amount of fuel-air mixture in the throat. Carburetors in the last group are usually found in ultralight aircraft, as well as slightly larger spark-ignition engines. Their operation mechanism is based on the ability to change the cross-sectional area of the throat, which is regulated by the pressure difference between the piston and atmospheric pressure. The area of lowest pressure is located behind the lowest point of the piston, while the engine power control lever is located behind the throttle and connected via a Bowden cable (Jakubowski, 2014).

3. Icing phenomenon

Aircraft surfaces and carburetors may become icy. It is explained as the process of creating ice on the surface of the aircraft,in particular on the front elements, which include the leading edges of the wings, vertical and horizontal empennage, propeller, carburetor, engine nacelle and intake system. The factors leading to this process include temperatures ranging from 21°C to -12°C (according to IMGW) (Balicki, Głowacki, Szczecinski, Chachurski, Szczeciński, 2014), pressure, air humidity, dew point temperature and the nature of clouds. Other important factors include: the angle of the air flow, the nature of the flow, the smoothness and contamination of the aircraft surface, and the granulometric composition of the water. Icing division in accordance with the guidelinesspeed of ice formation according to the Institute of Meteorology and Water Management (Jakubowski, 2014) include icing: weak, i.e., ice formation time up to 0.5 mm/min.

In the case of moderate icing, this time is extended and ranges from 0.5 to 1 mm/min. Heavy icing occurs at a rate of 1 to 2 mm/min. However, very heavy icing indicates the formation of ice at a rate above 2 mm/min. General carburetor icing is related to the formation of ice in the carburetor throat, on the throttle or in the bends of the intake system. This results in the throttle being blocked due to the accumulation of large amounts of ice or blockage of the nozzles and intake pipes. A graph illustrating the probability of icing is shown in figure (Figure 1).

Safety & Defense 10(2) (2024)
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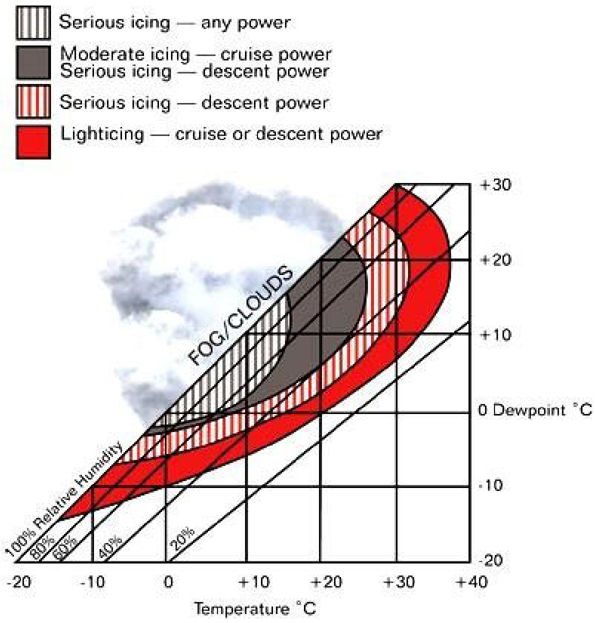

Figure 1. Graph of the probability of carburetor icing occurring. Adopted from: "An Icing Of Aircraft – Reasons, Consequences, Counteraction," by Gębura et al. Copyright 2014 by *Journal of KONBiN*.

The exact mechanism of carburetor icing formation explains that the airflow through the narrow part of the Venturi nozzle at the carburetor's inlet causes the airspeed to increase, while simultaneously reducing the air pressure and cooling it down. The injected fuel evaporates, drawing energy from the surrounding air, which causes the temperature to decrease further. When the air-fuel mixture is cold enough, meaning when the temperature drops below zero, carburetor icing may occur (Chachurski et al., 2005). It can happen in every phase of flight, but the risk order of these phases in terms of the greatest icing risk depends on the season. This is partly due to the phenomenon of inversion in the summer, which involves a simultaneous increase in temperature with altitude. This indicates that the surface temperature, for example, at the airport, will be lower than the temperature at the landing approach altitude and during flight. This can lead to ice buildup in the carburetor throat and on the throttle during descent (Brzęczek, 2019).

The phenomenon of carburetor icing can have serious consequences affecting flight safety, such as a reduction in the cross-sectional area of the carburetor throat, a decrease in the flow of the fuel-air mixture, disruption of engine operation, reduction of its power, and in extreme cases, engine shutdown. Typical locations of carburetor icing are shown in the figure (Figure 2).

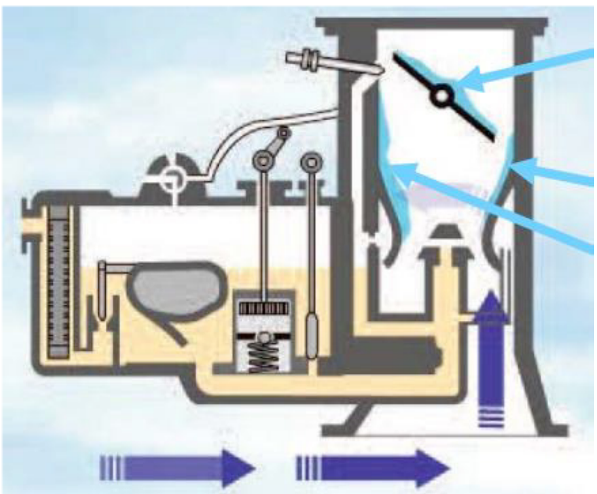

Figure 2. Typical carburetor icing places: throttle and carburetor throat walls. Adopted from: "Effect of the Atmosphere on the Performances of Aviation Turbine Engines," by Balicki et al. Copyright 2014, by *Acta Mechanica et Automatica*.

Safety & Defense 10(2) (2024)
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Carburetor icing is difficult to identify because, in the early stages of ice formation, it does not produce any clearly identifiable symptoms. Moreover, it is a very unpredictable process as it can occur at a wide range of temperatures and can be influenced by other factors. For a carburetor, this range is from -7°C to +21°C. It is worth noting, however, that there are documented cases of icing occurring at temperatures above 30°C (Gębura et al., 2015).

In aviation, a threat is understood as a condition in which a disruption occurs during a given aviation operation due to expected or completely unpredictable factors. In extreme cases, its occurrence can involve a chain of errors made gradually by the pilot, often resulting in aircraft accidents. Research conducted in the USA from 1990 to 2000 found that aircraft icing was the cause of up to 12% of all accidents. Of these, 52% concerned power systems, including elements of the intake system or carburetor. Aviation accidents can be visualized using various models describing the process. One of the most common models is the so-called Swiss Cheese model. This model distinguishes several key factors contributing to the initiation of an air accident, starting with the appearance of the threat. The other elements include safety culture, standard operating procedures, detailed mechanical attention, safety systems, pilot knowledge and preparation, pilot judgment, piloting skills, and luck.

The schematic shown in figure (Figure 3) illustrates symbolic slices of Swiss cheese in the context of factors affecting flight safety. It is worth noting that these factors apply to pilots, manufacturers, carriers, and other individuals and entities involved with the aircraft. The greatest responsibility, of course, lies with the pilots who conduct the flight. However, each of the aforementioned individuals may contribute to varying degrees to the risk of travel safety. For example, manufacturers are responsible for the production and design of aircraft, while carriers ensure that operational standards are maintained at a high level. The holes visible in the cheese slices represent imperfections in people and aircraft systems, suggesting dangers that cannot be entirely eliminated despite best efforts. If there were no holes in the symbolic slices, it would mean complete travel safety, which is practically impossible to achieve. Proper management of imperfections and the right selection of actions in the face of threats can reduce the risk to a minimum level and improve the level of safety. Later in the study, both symbolic slices and their holes will be highlighted (Liszkowska, 2018).

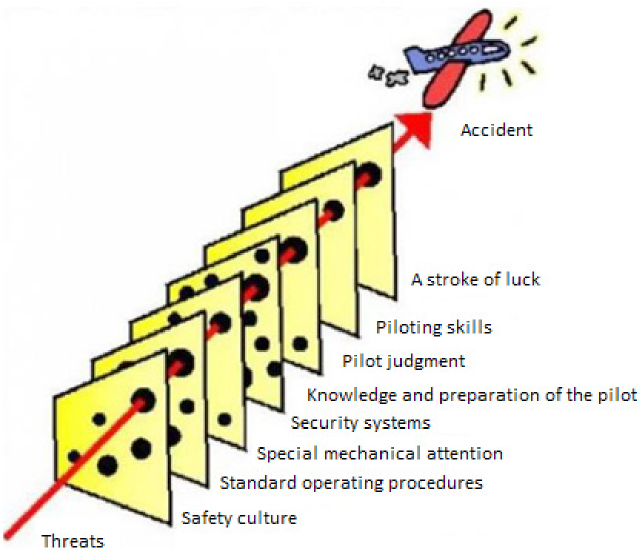

Figure 3. An example model of Swiss Cheese. Adopted from: " Zarządzanie zasobami załogi, czyli jak uniknąć błędów zarządczych", by Liszkowska. Copyright 2018, *Zeszyty Naukowe. Organizacja I Zarządzanie / Politechnika Łódzka*.

4. Aircraft accident analysis

The study focused on analyzing eighteen aircraft accident reports related to carburetor icing, selected from the PKBWL (State Commission for Aircraft Accident Investigation of Poland) report database over the past 20 years. The objective was to identify the main factors contributing to these accidents, determine their causes, and propose preventive solutions to reduce the risk of recurrence. The methodology involved a comprehensive review of external resources, specifically targeting reports of accidents linked to carburetor icing. Each selected report was thoroughly analyzed to interpret the flight course and the events leading to the accidents. The selection of these specific reports was based on their relevance to carburetor icing incidents, as well as their completeness in providing contextual data on contributing factors. By focusing on these cases, the analysis aims to address the

Safety & Defense 10(2) (2024)
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critical aspects of threat recognition and response in similar scenarios. The findings indicate that carburetor icing is a phenomenon that is challenging to detect; hence, understanding its characteristics is essential for implementing effective countermeasures.

5. Accident analysis results

The analysis of the available reports on air accidents revealed the most prevalent causes associated with carburetor icing incidents. A summary of these results is presented in the table below (Table 1). The leading cause identified was the failure to activate carburetor heating, which accounted for over 50% of the analyzed accidents. This oversight can be categorized under **Operator Error**, primarily attributed to a lack of awareness among pilots regarding the associated threats. Additionally, incidents related to carburetor icing were frequently linked to the incorrect interpretation of meteorological conditions, leading to flights conducted under hazardous circumstances that pilots often overlook or underestimate. This reflects another dimension of **Lack of Awareness** about the dangers posed by such weather conditions. Another significant factor was the delayed activation of carburetor heating, which also falls under operator error and increases the risk of icing. In some cases, icing occurred due to malfunctions in the carburetor heating system, indicating a **System Failure** that often resulted from inadequate pre-flight inspections or testing of the aircraft's power unit. Furthermore, the presence of water in the fuel emerged as an important factor contributing to icing under specific operating conditions of the carburetor. This issue again points to the necessity of thorough pre-flight checks, highlighting a systemic weakness in operational procedures. These findings underscore the necessity of enhanced training and awareness for pilots regarding the risks of carburetor icing and the importance of thorough pre-flight checks to mitigate these risks.

Table 1. List of causes of air accidents and proposed countermeasures

No.	Event no.	Cause of the event	Countermeasure
1.	191/03	**Operator Error:** Carburetor heating not turned on in icing conditions.	Improving the quality of training in the field of recognizing icing conditions and systematically checking pilots' knowledge in this field. Additionally, installation of temperature control devicesin the carburetor.
2.	199/03	**System Failure:** Damaged carburetor heating installation.	Introduction of additional training by the aviation center regarding pre-flight inspections and detection of potential faults. Additionally, installation of a special air inlet capable of separating water from the air, if possible.
3.	400/07	**Operator Error:** Bad weather conditions and too late switching on of the carburetor heating.	The aviation center increases the emphasis on learning meteorology in order to correctly read meteorological messages and recognize weather threats. Additionally, installation of temperature control devices in the carburetor.
4.	402/07	**Operator Error:** Carburetor heating not turned on in icing conditions.	Improving the quality of training in the field of recognizing icing conditions and systematically checking pilots' knowledge in this field. Additionally, installation of temperature control devicesin the carburetor.
5.	516/07	**Lack of Awareness:** Carburetor heating not turned on in icing conditions caused by lack of awareness of the danger.	Improving the quality of training in the field of recognizing icing conditions and systematically checking pilots' knowledge in this field. Increasing pilots' awareness of the threat by discussing aviation incidents. Additionally, installation of temperature control devicesin the carburetor.
6.	156/09	**Operator Error:** Carburetor heating switched on too late.	Introducing changes regarding training in the field of meteorology regarding the recognition of dangerous meteorological phenomena. Additionally, installation of devices that control the temperature in the carburetor.
7.	950/09	**System Failure:** Icing caused by water in the fuel.	Introducing mandatory pre-flight fuel checks for the presence of water and recording fuel checks in the logbook. Additionally, fuel inspection by more than one person to more accurately assess the presence of water in the fuel.
8.	136/11	**Lack of Awareness:** Bad weather conditions and lack of awareness of dangerous phenomena.	Introduction of routine checks on the knowledge of reading meteorological messages and recognizing meteorological phenomena.
9.	336/15	**Operator Error:** Bad weather conditions.	Control of the weather forecast by more than one person and the introduction of the principle of consulting the weather forecast with superiors at the aviation center.
10.	270/16	**Lack of Awareness:** Lack of knowledge on how to operate the anti-icing system.	Routine and detailed checks regarding knowledge of the aircraft operating manualin order to eliminate possible knowledge gaps in this area.
11.	2428/16	**Operator Error:** Bad meteorological conditions and poor assessment of meteorological conditions.	Introducing an opt-out policyfrom conducting a flight if the pilot is not sure of the meteorological conditions.

Safety & Defense 10(2) (2024)
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No.	Event no.	Cause of the event	Countermeasure
12.	2960/16	**System Failure:** Damaged carburetor heating system not detected during pre-flight inspection.	Introduction of additional training by the aviation center regarding pre-flight inspections and detection of potential faults. Additionally, performing an inspection by more than one person to check what the previous person checked to eliminate omissions. Also the installation of a special air intake capable of separating water from the air, if possible.
13.	2702/17	**Lack of Awareness:** Carburetor heating not turned on in icing conditions caused by lack of awareness of the danger.	Improving the quality of training in the field of recognizing icing conditions and systematically checking pilots' knowledge in this field. Increasing pilots' awareness of the threat by discussing aviation incidents. Additionally, installation of temperature control devicesin the carburetor.
14.	2729/19	**Operator Error:** Carburetor heating not turned on in icing conditions by disregarding the danger.	Regularly discuss aviation incidents involving carburetor icing to raise awareness among pilots of the serious dangers associated with this phenomenon. Additionally, installation of devices that control the temperature in the carburetor.
15.	2221/20	**Lack of Awareness:** Carburetor heating not turned on in icing conditions caused by failure to recognize the hazard.	Introduction of training in the field of dangerous meteorological phenomena and mandatory pre-flight weather consultation with superiors and instructors. Additionally, installation of devices that control the temperature in the carburetor.
16.	3656/20	**Operator Error:** Carburetor heating not turned on in icing conditions due to poor knowledge about this phenomenon.	Improving the quality of training in the field of recognizing icing conditions and systematically checking pilots' knowledge in this field. Increasing pilots' awareness of the threat by discussing aviation incidents. Additionally, discussing meteorological conditions before each flight with superiors and instructors. Also installation of temperature control devices in the carburetor.
17.	3777/20	**Lack of Awareness:** Carburetor heating not turned on in icing conditions caused by lack of awareness of the danger.	Introduction of a rule regarding periodic activation of the anti-icing system during the flight in order to eliminate more effective recognition of the icing phenomenon.
18.	1340/22	**Operator Error:** Carburetor heating not turned on in icing conditions.	Improving the quality of training in the field of recognizing icing conditions and systematically checking pilots' knowledge in this field.

An important role is not only assigned to direct causes but also to factors contributing to their occurrence. It is important to note that such factors are the first elements indirectly leading to the formation of icing. This is a large group in which special attention should be paid to the following:

- Lack of awareness among pilots about the existing threat, which often results in unrestricted flights in zones at risk of icing. This is also due to the mistaken belief that icing only occurs at negative temperatures.
- Insufficient training of staff in recognizing and preventing icing.
- Pilots' dismissive attitude toward the phenomenon of icing, which can lead to a lack of reaction to changing engine parameters and delays in or neglecting the attempt to heat the carburetor.
- Inaccurate pre-flight inspections and power unit tests, often due to haste. Such situations can lead to oversights and shortcomings, which may also result from ignorance or failure to respect flight instructions.
- Lack of knowledge on how to operate the carburetor heating, particularly in situations of immediate danger.

The above findings indicate that the main cause is the human factor.

There is a second, equally important problem stemming from the human factor, which is the element of surprise. Under the stress and disorientation of sudden detection and the impact of carburetor icing during the flight, pilots may make operational errors and incorrect decisions, which significantly affects travel safety.

6. Preventing carburetor icing

The analysis of reports regarding the causes and factors contributing to the formation of carburetor icing showed that it constitutes a serious problem and poses a significant threat to flight safety. Therefore, the key solution is to take preventive measures to minimize the likelihood of this threat occurring. In relation to the analyzed cases, proposals for preventive actions are presented in the table (Table 1).

A key solution may be to introduce fundamental changes in training programs aimed at improving their quality in the field of recognizing icing conditions, as well as systematic verification of pilots' knowledge in this area, particularly:

- Increasing emphasis on training in meteorology, especially the identification of icing hazards.
- Allowing for consultation in this area by another flight crew member or instructor, both during training and in normal aircraft operations.

Safety & Defense 10(2) (2024)
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- Conducting specific training on the construction and operation of heating installations and the conditions of their use.
- Implementing technical solutions that reduce the water content in intake air.
- Implementing technical solutions that result in continuous carburetor heating (from the oil pan or exhaust pipe).
- Equipping the aircraft with ambient temperature and carburetor indicators.

7. Summary

Summarizing the analysis carried out, the main causes of accidents and icing incidents can be indicated. They are listed below in order of prevalence:

- Not using carburetor heating.
- Performing flights in bad weather conditions and icing conditions.
- Turning on the carburetor heating too late.
- Damaged carburetor heating systems.
- Water in fuel.
- Lack of knowledge on how to operate the carburetor heater.

It is essential to clarify the terms “icing conditions” and “bad weather conditions.” While they may overlap, they are not necessarily the same. Icing conditions refer specifically to atmospheric conditions where the temperature is at or below freezing, combined with moisture in the air, which can lead to ice forming on critical aircraft components, including the carburetor. On the other hand, bad weather conditions encompass a broader range of adverse weather phenomena, such as heavy rain, thunderstorms, fog, or strong winds, which may not directly cause icing but can create hazardous flying conditions overall.

Despite the actual knowledge available on this subject, carburetor icing events remain a common cause of accidents. The main factor here is the human factor. Therefore, to reduce the number of these events, the main emphasis should be on addressing this factor. The following actions are proposed to reduce the number of related events:

- Improving the quality of training in recognizing icing conditions and systematically monitoring pilots’ knowledge in this area.
- Increasing emphasis by aviation centers on meteorology to correctly interpret meteorological messages and recognize weather threats.
- Introducing routine checks on the knowledge of interpreting meteorological messages and recognizing dangerous weather phenomena.
- Requiring the analysis of weather forecasts by more than one person and introducing the practice of consulting weather forecasts with superiors.
- Implementing additional training by aviation centers and organizations regarding pre-flight inspections, installation inspections, and detection of potential faults; additionally, conducting inspections by more than one person to eliminate oversights.
- Regular discussions of aviation incidents related to icing, including carburetor icing, to raise pilots’ awareness of the serious threat associated with this phenomenon.
- Routine and detailed checks of pilots’ knowledge of the aircraft operating manual.
- Installing devices to monitor temperature in the carburetor chamber and the external temperature.
- Eliminating water in fuel.

These countermeasures can effectively contribute to improving flight safety because they:

- Increase pilots’ awareness of the threat.
- Improve pilots’ appropriate responses.
- Prepare for proper hazard identification.
- Eliminate errors in preparation for flight.
- Improve pilot training procedures.

Declaration of interest
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

Safety & Defense 10(2) (2024)
DOI: https://doi.org/10.37105/sd.234

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